

Particle production in $p - p$ collisions at $\sqrt{s} = 17$ GeV within the statistical model

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A thermal-model analysis of particle production of $p - p$ collisions at $\sqrt{s} = 17$ GeV using the latest available data is presented. The sensitivity of model parameters on data selections and model assumptions is studied. The system-size dependence of thermal parameters and recent differences in the statistical model analysis of $p - p$ collisions at the super proton synchrotron (SPS) are discussed. It is shown that the temperature and strangeness undersaturation factor depend strongly on kaon yields which at present are still not well known experimentally. It is concluded, that within the presently available data at the SPS it is rather unlikely that the temperature in $p - p$ collisions exceeds significantly that expected in central collisions of heavy ions at the same energy.

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I. INTRODUCTION

The statistical model has been used to describe particle production in high-energy collisions for more than half a century [1]. In this period it has evolved into a very useful and successful model describing a large variety of data, in particular, hadron yields in central heavy-ion collisions [2, 3] have been described in a very systematic and appealing way unmatched by any other model. It has also provided a very useful framework for the centrality [4] and system-size dependence [5, 6] of particle production. The applicability of the model in small systems like $p - p$ [7] and $e^+ - e^-$ annihilation [8] has been the subject of several recent publications [9, 10, 11].

The statistical-model analysis of elementary particle interactions can be summarized by the statement that the thermal parameters show almost no energy dependence in the range of $\sqrt{s} = 14 - 900$ GeV with the temperature being about 165 MeV and the strangeness undersaturation factor γ_S being in the range between 0.5 and 0.7.

In the context of the system-size dependence of particle production, the $p - p$ collisions at $\sqrt{s} = 17$ GeV have been analyzed in detail recently. Based on similar data sets, the extracted parameters in different publications deviated significantly from each other: in a previous analysis (Ref. [5, 11]) we derived $T = 164 \pm 9$ MeV and $\gamma_S = 0.67 \pm 0.07$, with $\chi^2/n = 1.7/3$, while the authors in Ref. [6] obtained $T = 178 \pm 6$ MeV, $\gamma_S = 0.45 \pm 0.02$ with $\chi^2/n = 11/7$. These findings motivated different conclusions: In Ref. [5] no system size dependence of the thermal parameters was found, except for γ_S which tends to increase when more nucleons participate in the collisions but this rise is weaker than the errors on the strangeness suppression parameter. In Ref. [5] it was therefore concluded that the hadron gas produced in central collisions

at $\sqrt{s} = 17$ GeV reaches its limiting temperature. Based on Ref. [6] on the other hand, it was argued in Ref. [12] that, decreasing γ_S and, in particular, increasing temperature towards smaller systems allow for probing QCD matter beyond the freeze-out curve established in Pb-Pb and Au-Au collisions [13, 14].

The goal of this paper is to understand the origin of these rather different thermal-model results obtained in the analysis of $p - p$ data. We use an up-to-date complete set of data and discuss the sensitivity of the thermal model parameters on their values. We present systematic studies of data used as inputs and the methods applied in their thermal model analysis.

The paper is organised as follows: In Section II we discuss the experimental data on which different analysis are based. In Section III we summarize the main features of the statistical model and present the analysis of the SPS data obtained in $p - p$ collisions. In the final section we present our conclusions and summarize our results.

II. DATA

The data used throughout this paper for hadron yields in $p - p$ collisions at $\sqrt{s} = 17.3$ GeV are summarized in Table I. Data in column *Set A* were exploited in our previous analysis [11] and the corresponding references are given in the table. If the numerical values deviate in the analysis of Ref. [6], they are listed in column *Set B*. The relative differences between the particle yields from sets *A* and *B* are also indicated in Table I. The commonly used data in the statistical model description of particles production in $p - p$ collisions at the SPS are displayed below the horizontal line in Table I.

In Table II the experimental data are grouped in sets which are used in Section III to perform the Statistical

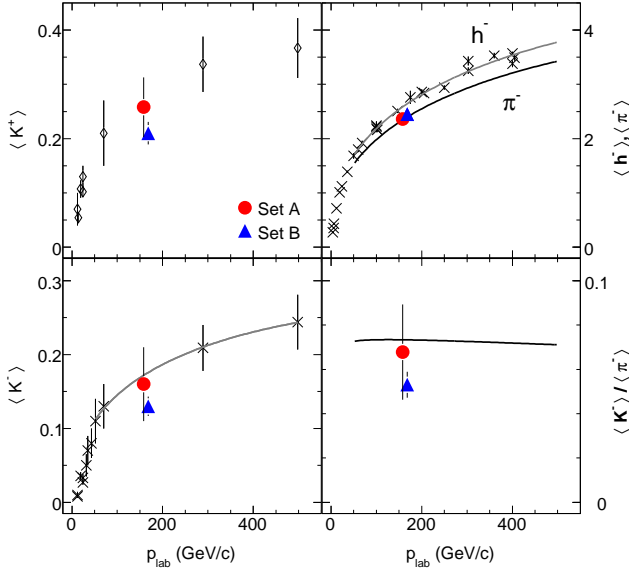


FIG. 1: Charged kaon yields (left panels), negatively charged hadron h^- and pions π^- (upper right) and K^-/π^- ratios (lower right panel) in $p-p$ collisions as a function of laboratory momentum. The charged kaons, K^+ (diamonds) and K^- (crosses) yields are from Ref. [22]. The lines are fits to data. The SPS yields from Ref. [16] (circle) and from Ref. [18] (triangle) are also shown. The negatively charged hadrons are from Ref. [23].

TABLE I: Particle yields (4π integrated) in minimum bias $p-p$ collisions at $\sqrt{s} = 17.3$ GeV. Numerical values of Set A are from Ref. [11]. For Set B and common values (data below the horizontal line) the references are given in the last column.

Particle	Set A	Set B	Δ_{yield}	Δ_{err}	Ref
π^+	3.02 ± 0.15	3.15 ± 0.16	4.4%	10.5%	[15]
π^-	2.36 ± 0.11	2.45 ± 0.12	3.8%	5.9%	[15]
K^+	0.258 ± 0.055				[16]
K^-	0.160 ± 0.050				[16]
K^+		0.210 ± 0.021	19%	62%	[18]
K^-		0.130 ± 0.013	19%	74%	[18]
Λ	0.116 ± 0.011	0.115 ± 0.012	0.9%	9.1%	[17]
$\bar{\Lambda}$	0.0137 ± 0.0007	0.0148 ± 0.0019	8.0%	171%	[17]
K_S^0	0.18 ± 0.04				[18]
\bar{p}	0.0400 ± 0.0068				[18]
Λ^*	0.012 ± 0.003				[19]
ϕ	0.0120 ± 0.0015				[20]
Ξ^-	0.0031 ± 0.0003				[21]
$\bar{\Xi}^+$	0.00092 ± 0.00009				[21]
Ω^-	0.00026 ± 0.00013				[21]
$\bar{\Omega}^+$	0.00016 ± 0.00009				[21]

Model analysis. In the following we motivate the particular choice of data in these sets and discuss how they can influence the model predictions on thermal conditions in $p-p$ collisions.

The data set A1 is most restricted. Firstly, the production yields of Ξ and Ω are not included because their numerical values are only preliminary (Ref. [21]). Secondly,

TABLE II: Different sets of particle yields used in the thermal model fits. The type A sets contain numerical values from the left (and common) columns of Table I. The type B sets contain data from Set B and common columns of Table I.

Set	Particles	Comment
A1	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p}$	Set of Ref. [11]
A2	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p} \Lambda^* \Xi^- \bar{\Xi}^+ \Omega^- \bar{\Omega}^+$	
A3	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p} \Lambda^* \phi$	
A4	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p}$	K^\pm from Ref. [18]
B1	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p} \Lambda^*$	Λ^* contribution
B2	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p} \Lambda^* \Xi^- \bar{\Xi}^+ \Omega^- \bar{\Omega}^+$	Fit A of Ref. [6]
B3	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p} \Lambda^* \phi$	Fit B of Ref. [6]
B4	$\pi^\pm K^\pm \Lambda \bar{\Lambda} K_S^0 \bar{p}$	Set B1 without Λ^*

the Λ^* resonance is also not included so as to restrict the analysis to stable hadrons. Finally, the ϕ meson is omitted in Set A1 since this particle is difficult to address in the statistical model due to its hidden strangeness as discussed in Ref. [5].

The lower yields of charged kaons in Set B of Table I are taken from results published in conference proceedings [18]. Such kaon yields are in disagreement with trends from data measured at lower and higher energies as seen in Fig. 1.

The left panels of Fig. 1 show the charged kaon multiplicities from $p-p$ interactions at lower and higher beam momenta [22] together with data from Table I. The lines in this figure are simple parametrizations interpolating to SPS energies. The K^- yield from [16] is seen to be 7% below the expected value from the above parametrization, however agrees within errors. The K^- abundance from [18] is by 24% lower and its error is only 10%. As we discuss below, such a low value for the multiplicity of charged kaons influences the statistical model fit in an essential way.

The upper right panel of Fig. 1 shows the negatively charged hadrons from $p-p$ interactions at several beam momenta from Ref. [23]. As indicated in Ref. [23] the K^- , \bar{p} and Σ^- supplement the π^- yield. In this case, the ratio π^-/h^- amounts to 91%. Including more sources of feed-down, the π^-/h^- ratio stays at the same level as long as Λ and K_S^0 can be separated. Consequently, to calculate the negatively charged pions from h^- yields one can use the above 91% scaling factor. Figure 1 (top right panel) shows the fit to h^- yields as a function of beam momenta and then by rescaling the expected result for the p_{lab} dependence of the negatively charged pions. The yields of π^- at SPS from Table I agree quite well with that expected from an interpolation line shown in Fig. 1. They are only slightly higher, by 1% for yields taken from [15] and by 5% for yields used in Ref. [6].

The lower right panel in Fig. 1 shows the K^-/π^- ratio at SPS compared to the interpolated data from other beam momenta. The mean value of the K^-/π^- used in [11] is 8% below the interpolated line but agrees within errors, while the corresponding value used in [6] is 28%

smaller and exhibits an error of only 11%. Clearly, the above differences in the K^-/π^- ratios influence the thermal model fits.

In general, a smaller kaon yield implies a stronger suppression of the strange-particle phase space resulting in a smaller value for the strangeness undersaturation factor γ_S . If other strange particles are included, then the strong suppression caused by γ_S has to be compensated by a higher temperature. This might be one of the origins for the different thermal fit parameters obtained in Refs. [11] and [6]. In order to quantify this we have selected a data set *A4* which is equivalent to the *Set A1* but with the kaon yields of Ref. [16] being replaced by the values from Ref. [18].

The *Set B1* is (besides the Λ^*) equivalent to *A1* but with numerical values for particle yields from column *B* in Table I. The *Set B4* is used to demonstrate the influence of the Λ^* resonance on thermal fit parameters. The *Sets A3, B3* and *A2, B2* are chosen to study the influence of the ϕ meson and the multistrange hyperons on thermal fit parameters.

III. STATISTICAL MODEL ANALYSIS

The usual form of the statistical model formulated in the grand-canonical ensemble cannot be used when either the temperature or the volume or both are small. As a rule of thumb one needs $VT^3 > 1$ for a grand-canonical description to hold [24, 25]. Furthermore, even if this condition is matched but the abundance of a subset of particles carrying a conserved charge is small, the canonical suppression still appears even though the grand-canonical description is valid for the bulk of the produced hadrons. There exists a vast literature on the subject of canonical suppression and we refer to several articles (see e.g. [3, 26, 27]).

The effect of canonical suppression in $p-p$ collisions at ultra-relativistic energies is relevant for hadrons carrying strangeness. The larger the strangeness content of the particle, the stronger is the suppression of the hadron yield. This has been discussed in great detail in [28].

In line with the previous statistical model studies of heavy-ion scattering at lower energies, the collisions of small ions at SPS revealed [5] that the experimental data show stronger suppression of strange-particle yields than what was expected in the canonical model [5, 29, 30]. Consequently, an additional suppression effect had to be included in order to quantify the observed yields. Here we introduce the off-equilibrium factor $\gamma_S \leq 1$ which reduces densities n_s of hadrons carrying strangeness s by $n_s \rightarrow n_s \cdot \gamma_S^{|s|}$ [25].

We investigate whether or not all quantum numbers have to be conserved exactly in $p-p$ collisions within a canonical approach by comparing data with two model settings:

- *Canonical (C) Model*: all conserved charges, i.e.

TABLE III: A list of parameters needed to quantify particle yields in the strangeness canonical (SC) and canonical (C) statistical model (see text). The symbols S, Q and B are the strangeness, electric charge and baryon number respectively with μ_i for $i = (S, Q, B)$ being chemical potentials related with conservation of these quantum numbers. γ_S is the strangeness undersaturation factor, T the temperature and R the radius describing the spherical volume of the collision zone.

	SC model		C model	
Fit parameter	μ_B	R	S	Q R
Constrained param.	μ_Q : $B/2Q = 0.5$		–	
Fixed param.	–		$B = 2$	
Fit / Scan param.	T	γ_S	T	γ_S
No. of parameter	5		6	
	Fit	χ^2 scan	Fit	χ^2 scan
No. of free param.	4	2	5	3
No. of fixed param.	1	3	1	3

strangeness, electric charge and baryon number are conserved exactly within a canonical ensemble.

- *Strangeness Canonical (SC) Model*: only strangeness is conserved exactly whereas the baryon number and electric charge are conserved on the average and their densities are controlled by the corresponding chemical potentials.

The parameters of these models are listed in Table III. In the following we compare predictions of the above statistical models with $p-p$ data summarized in different sets discussed above.

A. Comparative study of $p-p$ data at SPS

We start from the analysis of data set *A1* and modify it stepwise to find out in which way one matches the conclusion of larger temperature in $p-p$ than in central $A-A$ collisions at SPS as indicated in Ref. [6]. All numerical values of model parameters are listed in Table IV. A detailed discussion on their choice and correlations is presented in the Appendix based on the χ^2/n systematics.

The fit to data set *A1* in the SC model complies with our previous analysis from Ref. [11], see also Fig. 2 (top). The SC model fit to these data does not change when including Λ^* hyperons resulting in the same values of thermal parameters and their errors as summarized in Table IV.

The most striking effect on thermal parameters is expected when replacing the kaon yields in *Set A1* (Fig. 3, top) by those from Ref. [18], *Set A4*, Fig. 2 (bottom). Indeed, smaller kaon yields cause an increase of temperature and a decrease of γ_S . These changes come along with a reduced volume and in case of the SC fit with increase of the baryon chemical potential. The kaons from Ref. [18] dominate the fit because their errors are 10%

TABLE IV: Thermal parameters extracted within the strangeness canonical (SC) and canonical (C) model (see text) from fits to 4π -integrated data in $p-p$ collisions at $\sqrt{s} = 17.3$ GeV. In the SC model analysis for data set *B1* a fit does not converge, the minimum of the χ^2 scan is displayed. The fits to data sets *A3* and *B3* do not exhibit a χ^2 minimum in the parameter range considered, thus only the tentative parameters of a possible minimum are indicated.

SC model results					
Set	$T(\text{MeV})$	γ_S	$R \text{ (fm)}$	$\mu_B(\text{MeV})$	χ^2/n
A1	163 ± 5	0.68 ± 0.05	1.50 ± 0.11	208 ± 14	1.7/4
A2	168 ± 1	0.66 ± 0.02	1.37 ± 0.03	221 ± 8	8.6/9
A3	> 190	≈ 0.5	< 1.1	> 250	–
A4	177 ± 5	0.59 ± 0.03	1.23 ± 0.10	233 ± 16	5.1/4
B1	176	0.56	1.24 ± 0.01	240 ± 12	7.7/7
B2	179 ± 5	0.61 ± 0.02	1.19 ± 0.09	242 ± 18	16/9
B3	> 190	≈ 0.5	< 1.1	> 250	–

C model results					
Set	$T(\text{MeV})$	γ_S	$R \text{ (fm)}$		χ^2/n
A1	175 ± 5	0.57 ± 0.04	1.33 ± 0.09	–	0.5/3
A2	174 ± 4	0.59 ± 0.02	1.34 ± 0.08	–	6.6/8
A3	189 ± 5	0.46 ± 0.02	1.12 ± 0.09	–	23/5
A4	181 ± 4	0.52 ± 0.03	1.22 ± 0.07	–	3.5/3
B1	177 ± 5	0.51 ± 0.03	1.30 ± 0.09	–	6.8/4
B2	180 ± 4	0.56 ± 0.02	1.23 ± 0.08	–	18/8
B3	178 ± 5	0.45 ± 0.02	1.30 ± 0.10	–	19/5
B4	177 ± 5	0.50 ± 0.03	1.31 ± 0.09	–	4.8/3

while the uncertainties of the K^+ and K^- yields, taken from Ref. [16], are 21% and 31%, respectively. Consequently, the smaller errors dominate the statistical model fit.

In the next step we add Λ^* , Ξ and Ω hyperons resulting in *Set A2*, see Fig. 3, middle panel. The measured hyperon multiplicities coincide with the model results obtained before, thus within errors the statistical model parameters remain unchanged. We focus on *Set A3* and add the ϕ meson, Fig. 3 bottom. In this case the temperature is indeed much higher. In the SC model the thermal parameters obtained from the *Sets A3* and *B3* appear to be meaningless and unphysical due to the ϕ meson contribution.

Additional to different kaon data in *Sets A* and *B* there are also slightly different values for pions and Λ yields, see Table I. Compared to results obtained from data *Sets A4*, in the fit of *Set B1* the higher pion yield reduces the strange to non-strange particle ratios resulting in slightly smaller value of γ_S . The fit obtained with the *Set B4* yields similar results as that obtained from *Set B1* indicating that the Λ^* resonance does not affect the model parameters.

In the canonical (C) model analysis the *Sets A1* and *A2* tend towards a slightly higher temperature and smaller γ_S than that obtained in the SC analysis. The situation is different for *Sets A3* and *B3* that include the ϕ meson. Here in the SC model the temperature is very high and $\gamma_S \simeq 0.5$. In the C model the temperature decreases and

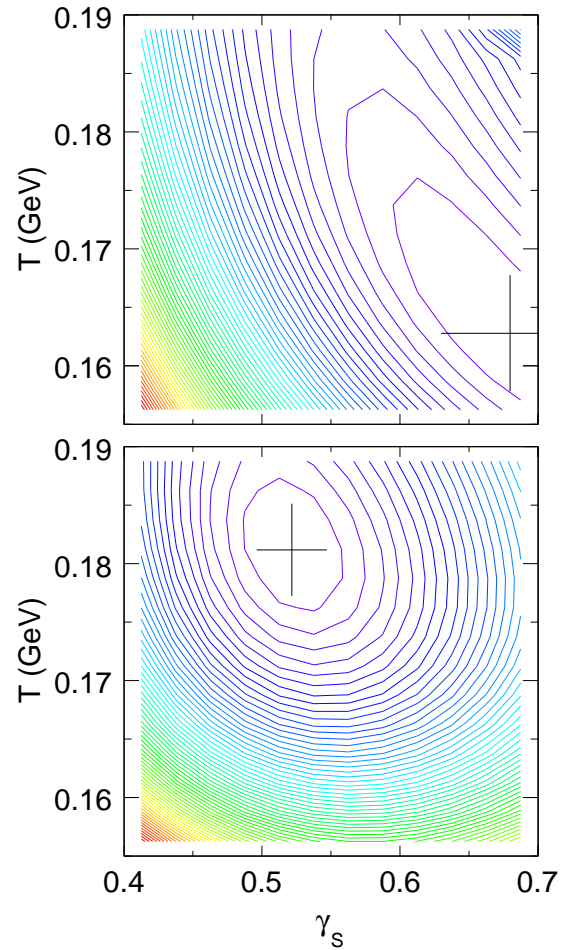


FIG. 2: The χ^2 scan in the $(T-\gamma_S)$ -plane. Starting from its minimum, χ^2 increases by 2 for each contour line. Upper figure: fit to data set *A1* in the model where only strangeness is conserved exactly (SC). Lower figure: fit to data set *A4* in the canonical (C) model. The minima are indicated by the crosses.

γ_S drops below 0.5. We can conclude that in the case where the ϕ meson is included in the fit, one needs to apply the C analysis to get lower temperatures, however with very small values of γ_S and a large χ^2/n . For *Set B3* the numerical results for T and γ_S summarized in Table IV coincide with that obtained in Ref [6], however with a larger χ^2/n [31].

IV. DISCUSSION AND SUMMARY

The statistical-model analysis of hadron yields for $p-p$ collisions at $\sqrt{s} = 17$ GeV from Refs. [5] and [6], yield different results and lead to different conclusions on the system-size dependence of thermal parameters [5, 12]. In this paper we have reanalyzed the $p-p$ data and studied the sensitivity of the thermal fit to data selection and on model assumptions. We have shown that different

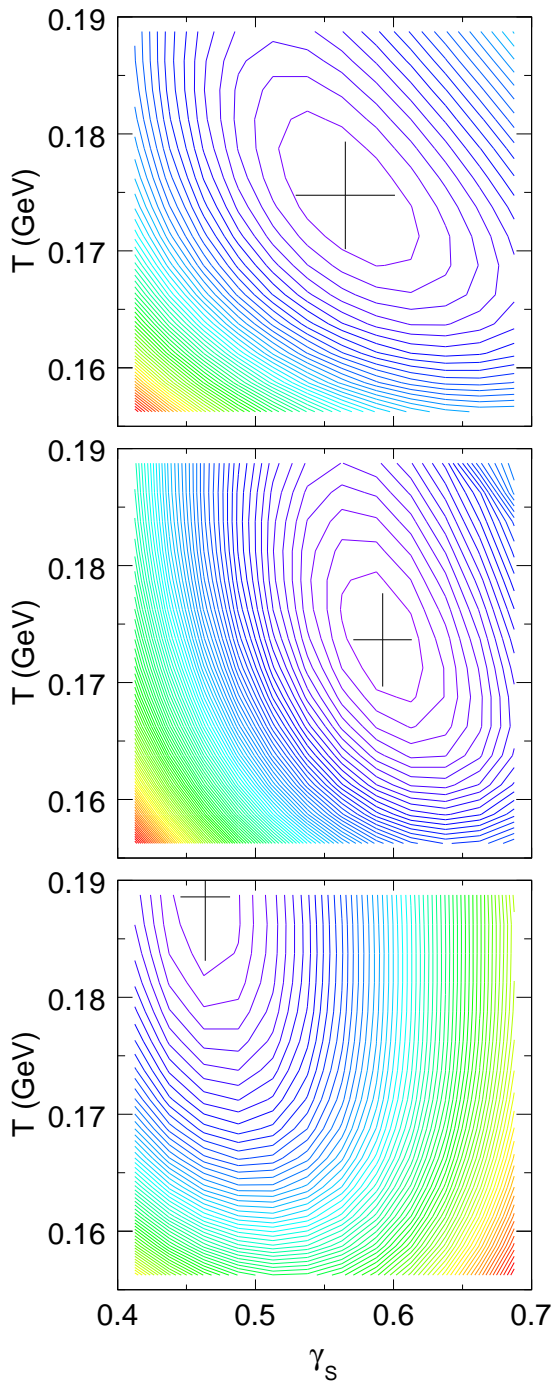


FIG. 3: As in Fig. 2 but for data Set A1 (top), Set A2 (middle), Set A3 (bottom). Canonical ensemble.

conclusions from Refs. [5] and [6] are mostly due to differences in data selections.

Slightly different numerical values for charged pions and Λ hyperons used in Refs. [5] and [6] as well as the contribution of the Λ^* resonance altered thermal parameters only within errors. However, the used charged kaon yields in both approaches differ substantially. We have argued that data of kaon yields in Ref. [6] deviate from

trends seen in data at different energies resulting in a higher temperature.

We have shown that higher kaon yields expected from the systematics in the energy dependence in $p - p$ collisions are in line with data on multi-strange baryons. Unlike the hyperons, when adding the ϕ meson the thermal model fit leaves a reasonable range of parameters resulting in a very high temperature exceeding 190 MeV and large χ^2/n . We have quantified the modifications of these results when including an exact conservation of all quantum numbers in the canonical statistical model. We have shown that in the absence of ϕ meson the thermal fits are rather weakly influenced by canonical effects due to an exact conservation of the baryon number and an electric charge leading in some cases to a systematic increase of the freezeout temperature. Fits including the ϕ meson are sensitive to an exact conservation of all quantum numbers resulting in lower temperatures. However, the thermal model analysis of data sets with hidden strangeness has the largest χ^2/n indicating that this particle cannot be addressed properly in this model.

From our analysis, we conclude that within the presently available data on $p - p$ collisions at SPS energy and uncertainties on thermal parameters obtained from fits within the statistical model, it is rather unlikely that the temperature in $p - p$ collisions exceeds significantly that expected in central collisions of heavy ions at the same energy.

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APPENDIX A: THE χ^2 CONTOURS OF THERMAL FITS

In this appendix we quantify the choice of thermal parameters within the statistical model through χ^2 -contours in the parameter space. Since the temperature T and γ_s are of particular interest here the quality of the fits are shown in Figs. 2 and 3 in the $(T - \gamma_s)$ -plane. In these figures for fixed (T, γ_s) -pair the remaining model parameters were fitted and the corresponding χ^2 was calculated.

Figure 2 (top) shows the analysis of the data Set A1 within the strangeness canonical (SC) model. The analysis in the model with canonical treatment of all conserved charges (C) is shown in Fig. 3 for all data sets besides the Set A4 which is presented in Fig. 2 (bottom).

In the C model description of data Set A1 there is a large region of a very low χ^2 which manifests the expected

anti-correlation of T and γ_S . Reasonable fits are possible over a large range of parameters. For the *Set A2* the minimum is located at the same temperature and slightly higher γ_S . The contributions of Ξ and Ω baryons disfavor small values of γ_S .

The ϕ , as seen in Fig. 3, directs fits towards very high temperatures and very strong strangeness suppression. Also the pattern of $(T-\gamma_S)$ anti-correlations shows decreasing χ^2 with increasing temperature at fixed γ_S .

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- [1] E. Fermi, *Progress Theor. Phys.* **5**, 570 (1950); W. Heisenberg, *Naturwissenschaften* **39**, 69 (1952); R. Hagedorn, *Nuovo Cimento* **35**, 395 (1965).
 - [2] P. Braun-Munzinger, I. Heppe and J. Stachel, *Phys. Lett. B* **465**, 15 (1999); F. Becattini, J. Cleymans, A. Keranen, E. Suhonen and K. Redlich, *Phys. Rev. C* **64**, 024901 (2001); P. Braun-Munzinger, D. Magestro, K. Redlich and J. Stachel, *Phys. Lett. B* **518**, 41 (2001); N. Xu and M. Kaneta, *Nucl. Phys. A* **698**, 306 (2002); F. Becattini, *J. Phys. G* **28**, 1553 (2002); A. Andronic, P. Braun-Munzinger and J. Stachel, *Nucl. Phys. A* **772**, 167 (2006).
 - [3] P. Braun-Munzinger, K. Redlich and J. Stachel, in *Quark-Gluon Plasma 3*, Eds. R.C. Hwa and X.N. Wang, (World Scientific Publishing, 2004).
 - [4] J. Cleymans, B. Kämpfer, M. Kaneta, S. Wheaton and Nu Xu, *Phys. Rev. C* **71**, 054901 (2005); J. Cleymans, B. Kämpfer and S. Wheaton, *Phys. Rev. C* **65**, 027901 (2002).
 - [5] I. Kraus, J. Cleymans, H. Oeschler, K. Redlich and S. Wheaton, *Phys. Rev. C* **76**, 064903 (2007).
 - [6] F. Becattini, J. Manninen and M. Gazdzicki, *Phys. Rev. C* **73**, 044905 (2006).
 - [7] F. Becattini and U. W. Heinz, *Z. Phys. C* **76**, 269 (1997).
 - [8] F. Becattini, *Z. Phys. C* **69**, 485 (1996); *J. Phys. G* **23**, 1933 (1997);
 - [9] A. Andronic, F. Beutler, P. Braun-Munzinger, K. Redlich and J. Stachel, arXiv:0804.4132 [hep-ph];
 - [10] F. Becattini, P. Castorina, J. Manninen and H. Satz, arXiv:0805.0964 [hep-ph].
 - [11] I. Kraus, J. Cleymans, H. Oeschler and K. Redlich, *Phys. Rev. C* **79**, 014901 (2009).
 - [12] M. Gazdzicki, arXiv:0801.4919 [nucl-ex].
 - [13] J. Cleymans and K. Redlich, *Phys. Rev. Lett.* **81**, 5284 (1998).
 - [14] J. Cleymans and K. Redlich, *Phys. Rev. C* **60**, 054908 (1999); J. Cleymans, H. Oeschler, K. Redlich and S. Wheaton, *Phys. Rev. C* **73**, 034905 (2006).
 - [15] C. Alt et al. (NA49 Collaboration), *Eur. Phys. J. C* **45**, 343 (2006).
 - [16] A. M. Rossi et al., *Nucl. Phys. B* **84**, 269 (1975).
 - [17] T. Anticic et al. (NA49 Collaboration), *Phys. Rev. Lett.* **93**, 022302 (2004).
 - [18] J. Baechler et al. (NA49 Collaboration), *Nucl. Phys. A* **661**, 45 (1999).
 - [19] S. V. Afanasiev et al. (NA49 Collaboration), *J. Phys. G* **27**, 367 (2001).
 - [20] S. V. Afanasiev et al. (NA49 Collaboration), *Phys. Lett. B* **491**, 59 (2000).
 - [21] These numbers were taken from a compilation of NA49 data available on their web page <http://na49info.web.cern.ch/na49info/na49/>. They are preliminary, unpublished data taken from a PhD thesis. For a detailed discussion see section II.
 - [22] M. Gazdzicki and D. Roehrich, *Z. Phys. C* **71**, 55 (1996).
 - [23] M. Gazdzicki and D. Roehrich, *Z. Phys. C* **65**, 215 (1995).
 - [24] R. Hagedorn and K. Redlich, *Z. Phys. C* **27**, 541 (1985).
 - [25] J. Rafelski and M. Danos, *Phys. Lett. B* **97**, 279 (1980); B. Müller and J. Rafelski, *Phys. Lett. B* **116**, 274 (1982).
 - [26] J. Cleymans, K. Redlich, H. Oeschler and A. Tounsi, *Acta Physics Polonica B* **33**, 1609 (2002).
 - [27] J. Cleymans, H. Oeschler and K. Redlich, *Phys. Rev. C* **59**, 1663 (1999); *Phys. Lett. B* **485**, 27 (2000). P. Braun-Munzinger, J. Cleymans, H. Oeschler and K. Redlich, *Nucl. Phys. A* **697**, 902 (2002). J. Cleymans, A. Forster, H. Oeschler, K. Redlich and F. Uhlig, *Phys. Lett. B* **603**, 146 (2004).
 - [28] S. Hamieh, K. Redlich and A. Tounsi, *Phys. Lett. B* **486**, 61 (2000).
 - [29] I. Kraus, H. Oeschler and K. Redlich, *Eur. Phys. J. C* **49**, 109 (2007).
 - [30] I. Kraus, H. Oeschler, K. Redlich, PoS(HEP2005)140 (web only, <http://pos.sissa.it/>), arXiv:hep-ph/0604242.
 - [31] We compare our results to fit B from Ref [6]